Published in final edited form as:
Arch Environ Occup Health. 2017 November 02; 72(6): 313–316. doi:10.1080/19338244.2017.1288077.

Heat exposure and productivity in orchards: Implications for climate change research

Grant Quiller, MS[1], **Jennifer Krenz, MS, MPH**[1], **Kristie Ebi, PhD, MPH, MS**[1,2], **Jeremy J. Hess, MD, MPH**[1,2,3], **Richard A. Fenske, PhD, MPH**[1], **Paul D. Sampson, PhD**[4], **Mengjie Pan, BA**[4], and **June T. Spector, MD, MPH**[1,3,§]

[1]Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington, United States

[2]Department of Global Health, University of Washington, Seattle, Washington, United States

[3]Department of Medicine, University of Washington, Seattle, Washington, United States

[4]Department of Statistics, University of Washington, Seattle, Washington, United States

Abstract

Recent studies suggest that heat exposure degrades work productivity, but such studies have not considered individual- and workplace-level factors. Forty-six tree fruit harvesters (98% Latino/a) from six orchards participated in a cross-sectional study in Central/Eastern Washington in 2015. The association between maximum measured work-shift Wet Bulb Globe Temperature ($WBGT_{max}$) and productivity (total weight of fruit bins collected per time worked) was estimated using linear mixed effects models, adjusting for relevant confounders. The mean (standard deviation) $WBGT_{max}$ was 27.9 (3.6)° C in August and 21.2 (2.0) °C in September. There was a trend of decreasing productivity with increasing $WBGT_{max}$, but this association was not statistically significant. When individual- and workplace-level factors were included in the model, the association approached the null. Not considering individual, work, and economic factors that affect rest and recovery in projections of the impacts of climate change could result in overestimates of reductions in future productivity and underestimate risk of heat illness.

Introduction

Heat-related illness (HRI) is an important public health problem for workers exposed to heat sources indoor and out. United States Bureau of Labor Statistics data indicate that 359 occupational heat-related deaths occurred between the years of 2000 and 2010, and agricultural workers had the highest heat-related mortality rate (3.1 per million worker-years)[1]. In addition, several studies reported associations between heat exposure and productivity[2–4]. The effect of heat exposure on productivity not only has economic implications[5] but may also be considered by employers when deciding whether to prioritize workplace heat stress controls.

[§]Corresponding author: June Spector, Departments of Environmental & Occupational Health Sciences and Medicine, 1959 NE Pacific Street, Seattle, WA 98195, Phone: 206 897-1979, spectj@u.washington.edu.

Competing financial interests declaration: The authors declare they have no actual or potential competing financial interests.

Although several studies in India reported decreases in productivity with increases in heat exposure[2–4], these studies did not consider individual and work-related factors that may be associated with heat exposure and productivity, such as individual work experience and payment schemes. Studies projecting dramatic reductions in productivity in future years due to climate change assumed worksites adhere to existing occupational health guidelines for reducing the amount of time laboring at higher heat exposures[6–8].

We sought to estimate associations between heat exposure and productivity in a cross-sectional sample of 46 tree fruit harvesters in Central/Eastern Washington during the 2015 harvest season, taking into account potential individual and work-related confounders. This population of workers is already exposed to heat stress during a typical harvest season, and heat exposure is expected to increase over the next century based on climate model projections[9].

Methods

Study sites and population

A convenience sample of orchards and adult (age 18 or older) piece-rate (paid by the amount of fruit harvested) tree fruit harvesters from Central/Eastern Washington were recruited through University of Washington (UW) Pacific Northwest Agricultural Safety and Health Center contacts in 2015. Forty-six harvesters (34 during August pear harvest and 12 during September apple harvest) from six orchards (five pear orchards and one apple orchard) participated for one work-shift each. Study procedures were reviewed and approved by the UW Institutional Review Board, and participants provided informed consent prior to participation.

Individual and work-related factors

Individual factors were assessed using an audio computer-assisted self-interview survey instrument on tablet computers[10]. Height and weight were measured to calculate body mass index (BMI [kg/m^2])[11]. Individual clothing, work and break timing, productivity (number of bins of fruit harvested), and price paid per bin were assessed using field observations.

Heat stress and heat strain

Wet Bulb Globe Temperatures (WBGTs) were measured using a hand-held WBGT monitor (Extech HT30 WBGT Meter, Extech Instruments; Nashua, NH) near individual workers approximately every one to three hours. Workers' core body temperatures and heart rates were continuously monitored using CorTemp™ wireless ingestible sensors (HQ Inc; Palmetto, FL) and Polar® chest band monitors (Polar Inc; Lake Success, NY), respectively. Heat stress and strain were assessed for each worker using methods adapted from American Conference of Governmental Industrial Hygienist (ACGIH) guidelines[12]. All workers were categorized based on field observations as performing moderate metabolic rate (300 Watt) work activities with 75–100% allocation of work in a work/recovery cycle.

Statistical analysis

The association of daily maximum measured WBGT ($WBGT_{max}$) with productivity (mean kg/hour) was modeled using linear mixed effects models with intercept random effects for worksites, using the Kenward-Rogers method for small samples[13,14]. We considered a number of potential confounders, hypothesized to be related to both heat exposure and productivity, coded as follows: work experience (<1 [reference category], 1–2, 3–5, 6–9, >9 years), gender (male [reference category], female), price paid per bin ($15/bin [reference category], $19/bin, and ≥$21/bin), BMI, and shift duration. Clothing was not included in models because of a lack of substantial variability among workers in type of clothing worn, and age was also not included because it was highly related to years of work experience. Analyses were conducted using R 3.2.5 (R Foundation, Vienna, Austria)[15].

Results

Characteristics of the study population are shown in Table 1. The mean (standard deviation) $WBGT_{max}$ during participants' work shifts was 27.9 (3.6)° C in August (range: 22.0–33.1° C) and 21.2 (2.0) °C in September (range: 19.0–22.9°C). Twenty-five (74%) of workers exceeded the ACGIH Heat Stress Action Limit (AL) (WBGT 25°C) and 15 (44%) exceeded the Threshold Limit Value (TLV) (WBGT 28°C) in August. No workers exceeded the ACGIH AL or TLV in September. Fifty-four percent of those exceeding the AL exceeded the maximum recommended heart rate (sustained heart rate for several minutes above 180 beats per minute minus the age of the worker) or core temperature (38.5°C) for acclimatized workers, per ACGIH guidelines[12], indicating heat strain. The mean (standard deviation) time-weighted average WBGT was 22.3 (2.5) °C in August and 15.9 (1.0) °C in September.

Estimates of the association between $WBGT_{max}$ and productivity are shown in Table 2. There was a trend of decreases in productivity with increases in $WBGT_{max}$ in the unadjusted model (−4.8 kg/hr change in productivity for every one degree Celsius increase in $WBGT_{max}$ [95% confidence interval −16.3, 6.6]), but this effect approached the null after adjustment for potential confounders (−0.7 [95% confidence interval −19.8, 18.4]). Sensitivity analyses that included only August pear harvesters and only males yielded similar inferences.

Discussion

Our finding of a trend of decreased productivity with increased $WBGT_{max}$ in an unadjusted model, although not statistically significant, is consistent with previous studies[2,3,5]. However, after adjustment for confounders, the association approached the null. Analyses including individual and work-related characteristics provided nuanced implications for possible changes in worker productivity associated with a changing climate.

An often cited study by Sahu et al[2] reported a negative association between productivity and WBGT in rice harvesters in India and serves as seminal work demonstrating potential impacts of climate change on productivity. Heat exposures were substantially higher than in our study, and Indian workers were able to pace themselves. Differences in acclimatization and cultural and socioeconomic factors such as hydration practices and access to good nutrition and clean water may have also influenced productivity and contributed to differences in findings between Indian workers and our primarily Latino study population.[2,16] Workers in our study were paid by the amount harvested (piece-rate) so were incentivized to harvest quickly. This incentive may counter the human body's natural response to slow down when experiencing heat stress to minimize the amount of heat generated from heavy physical work[17]. Therefore, workers in our study may have been less likely to exhibit reduced productivity in the heat but at greater risk for HRI. This suggests that worker productivity may not decline as much as projected under climate change, but HRI rates could increase depending on incentive schemes.

It is possible that productivity may decrease with increasing price paid per bin because workers may have a personal economic target resulting in a need to fill fewer bins if the price paid per bin is higher. Lower productivity may occur when workers are less experienced and have longer shift durations. Working longer hours to harvest trees with less readily accessible fruit may be less efficient. Projecting climate change effects on productivity under different future socioeconomic conditions is challenging.

It was apparent in orchard workers in our study that rest periods, which normally allow workers to stay below ACGIH heat stress ALs and TLVs, were often not adequate. Given that worksites do not always adhere to occupational health guidelines presently, our results do not support climate change projections that assume adherence to standards and guidelines in the future[7–8]. This assumption can introduce a bias that results in an overestimation of the impact of climate change on decreases in worker productivity and an underestimation of the impact of climate change on HRI rates.

Limitations

This study has several limitations. First, several orchard factors that could influence variability in productivity between orchards were not assessed. These include differences in management practices, harvesting practices, tree growth and condition, and terrain. It was difficult to differentiate crop from orchard differences because there was only one participating apple orchard, and apple harvesters participated during the cooler September month. Second, ACGIH methods are not intended for use at the individual level, although individual heat strain assessments are recommended at exposures above the AL. Ambient heat exposure varies within orchards[18], and job-based assessments do not take into account this microclimate variability. Third, the analysis of the association between WBGT and productivity was limited by a small sample size, with data collected during only one work shift per participant. Future studies should address this question with more statistical power and ideally with repeated measures. Finally, findings from this study in Latino workers in Central/Eastern Washington may not be generalizable to other settings, climates, and populations.

Conclusion

Overall, our results suggest the need for more nuance when projecting the impacts of climate change on worker productivity. The relationship between heat exposure and productivity in outdoor workers is complex and likely affected by economic factors and work characteristics that drive endogenous heat load. Realistic assumptions and sensitivity analyses regarding work-rest cycles and consideration of factors other than heat that affect productivity are needed. Not considering these factors could lead to overestimates of the impacts of climate change on productivity in outdoor workers and, potentially, to underestimates of the incidence of work-related heat illness.

Acknowledgments

The authors would like to acknowledge Pablo Palmandez, Maria Negrete, Jose Carmona, and Miriam Calkins for their assistance with data collection. The work was funded by CDC/NIOSH 5K01OH010672-02 (PI Spector).

References

1. Gubernot DM, Anderson GB, Hunting KL. The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. Int J Biometeorol. 2014; 58(8):1779–1788. [PubMed: 24326903]
2. Sahu S, Sett M, Kjellstrom T. Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. Ind Health. 2013; 51:424–431. Japan. [PubMed: 23685851]
3. Lundgren K, Kuklane K, Gao C, Holmer I. Effects of heat stress on working populations when facing climate change. Ind Health. 2013; 51(1):3–15. [PubMed: 23411752]
4. Sett M, Sahu S. Effects of occupational heat exposure on female brick workers in West Bengal, India. Glob Health Action. 2014; 7:21923. Sweden.
5. Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST. Heat stress causes substantial labour productivity loss in Australia. Nature Clim Change. 2015; 5(7):647–651.
6. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. Glob Health Action. 2009:2.
7. Dunne JP, Stouffer RJ, John JG. Reductions in labour capacity from heat stress under climate warming. Nature Clim Change. 2013; 3(6):563–6.
8. Kjellstrom T. Impact of Climate Conditions on Occupational Health and Related Economic Losses: A New Feature of Global and Urban Health in the Context of Climate Change. Asia Pac J Public Health. 2015
9. Mote PW, Salathé EP. Future climate in the Pacific Northwest. Climate Change. 2010
10. Spector JT, Krenz J, Blank KN. Risk Factors for Heat-Related Illness in Washington Crop Workers. J Agromedicine. 2015; 20(3):349–359. [PubMed: 26237726]
11. Centers for Disease Control and Prevention. How is BMI calculated and interpreted. 2011.
12. American Conference of Governmental Industrial Hygienists (ACGIH). Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati: American Conference of Governmental Industrial Hygienists; 2015.
13. Kenward MG, Roger JH. Small sample inference for fixed effects from restricted maximum likelihood. Biometrics. 1997; 53(3):983–997. [PubMed: 9333350]
14. Halekoh U, Højsgaard S. A kenward-roger approximation and parametric bootstrap methods for tests in linear mixed models–the R package pbkrtest. Journal of Statistical Software. 2014; 59(9): 1–30. [PubMed: 26917999]
15. Team RC. R: A language and environment for statistical computing. Vienna, Austria: 2013.
16. Lam M, Krenz J, Palmandez P, Negrete M, Perla M, Murphy-Robinson H, et al. Identification of barriers to the prevention and treatment of heat-related illness in Latino farmworkers using activity-oriented, participatory rural appraisal focus group methods. BMC Public Health. 2013; 13:1004. [PubMed: 24156496]
17. Sawka MN, Leon LR, Montain SJ, Sonna LA. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Compr Physiol. 2011; 1(4):1883–1928. [PubMed: 23733692]

18. Snyder R, Connell J. Ground cover height affects pre-dawn orchard floor temperature. California Agriculture. 1993; 47(1):9–12.

Table 1

Characteristics of study population (n=46)

Characteristic	Percent or mean (standard deviation)
Male	84.8%
Latino/a	98.0%
Born in Mexico/Central America	96.0%
Age *	39.1 (14.1)
Body mass index (kg/m^2)	27.9 (4.2)
Daily hours worked	6.8 (1.5)
Reported heat-related symptoms * φ	52.2%
Years of work experience *	
< 1	10.9%
1–2	6.5%
3–5	8.7%
6–9	8.7%
> 9	65.2%
Price paid per bin	
$15	26%
$19	41%
>=$21	33%
Total kilograms harvested per hour worked	340.7 (84.2)

* Self-reported responses

φ Self-reported symptoms of dizziness/light-headedness or heavy sweating in the previous week

Table 2

Effect estimates and 95% confidence intervals from adjusted linear mixed effect model of productivity with random intercept for worksite

Characteristic	Unadjusted effect estimate (95% confidence interval)	Adjusted effect estimate (95% confidence interval)*
Max measured work-shift wet bulb globe temperature	−4.8 (−16.3, 6.6)	−0.7 (−19.8, 18.4)
Female (ref. male)	--	−22.7 (−106.2, 60.8)
Experience (ref. < 1 year)	--	--
1–2 years	--	22.9 (−109.1, 155.0)
3–5 years	--	104.7 (−42.1, 251.5)
6–9 years	--	92.0 (−21.3, 205.3)
> 9 years	--	54.6 (−29.0, 138.1)
Body mass index (kg/m^2)	--	−4.6 (−11.0, 1.8)
Price per bin (ref. $15)	--	--
$19	--	−37.0 (−488.6, 414.6)
$21 or $25	--	−67.9 (−373.9, 238.0)
Shift duration	--	−1.1 (−27.0, 24.8)

*Adjusted for all variables in table